

# AWARE: Technologies for Interpreting and Presenting Aviation Weather Information

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*Abstract*— NASA recently initiated a large multi-year program to develop technologies that will reduce aviation accidents and fatalities attributable to weather. Weather is a substantial contributor to many general aviation (GA) accidents. A large percentage of GA accidents are caused by non-instrument-rated pilots inadvertently flying into instrument meteorological conditions (IMC), or instrument-rated pilots flying into catastrophic weather conditions such as thunderstorms, severe downdrafts, and low-level windshear. A team led by Rockwell Science Center is working on a project to facilitate weather awareness for the GA pilot. AWARE is an enhanced weather briefing and reporting tool that integrates text-based and graphical aviation weather data for superior situational awareness in the context of a mission and equipment profile. AWARE is designed to benefit GA pilots who, due to cognitive overload, may not absorb and retain all flight-critical weather information from a vast stream of data they are legally required to review.

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### 1. INTRODUCTION

In 1997, a White House commission on aviation safety led by Vice President Gore issued a mandate to reduce accident rates by a factor of five in the next ten years, and by a factor of ten within 20 years. NASA responded to this mandate by organizing an aviation safety investment strategy team (ASIST), whose efforts culminated in the foundation of the NASA Aviation Safety Program (AvSP). AvSP aims to provide research and technology products needed to help the FAA and the industry achieve the ambitious target of reducing accident rates by 80% within the next ten years.

As part of AvSP, NASA recently initiated a large multi-year program named AWIN (Aviation Weather Information) to develop technologies that will eventually

reduce aviation accidents and fatalities attributable to weather [1]. Eight cooperative research agreements were awarded under this program. Four of the research agreements address aviation weather information system development; the other four are "topical" proposals that aim to solve particular problems instead of focusing on system deployment issues. These agreements were awarded for an 18-month Phase 1 R&D effort with an optional three year extension beyond that period. The programs are cost-shared by NASA and the industry, and particular emphasis is given to early deployment of successful technologies. Most of the projects are underway as of October 1998. Table 1 lists the eight AWIN programs.

This paper will discuss AWARE (Aviation Weather Awareness and Reporting Enhancements), one of the four topical projects initiated under the AWIN program. The program has officially started in October 1998 and is expected to continue through FY'2002. Since many of the technologies proposed under the AWARE program are not yet implemented, the paper will concentrate on the concepts and technologies that are currently available and will be incorporated in the program.

### 2. WEATHER FOR GENERAL AVIATION

#### *Preflight Weather Briefing*

General Aviation (GA) has not been one of the prime beneficiaries of the computing revolution that has drastically changed our lives. Using inexpensive computers, we can now receive real-time stock quotes, buy and sell cars, search and access vast streams of information, and engage in interactive communications with colleagues and friends. Yet, the means by which we access aviation weather information have not changed for the better since the '70s. The gold standard of aviation weather briefing, the professional weather briefer who interprets raw weather data based on the declared needs of a pilot, is slowly being replaced by automated services. Although commercial services such as Direct User Access Terminal (DUAT) can provide vast amounts of data for the pilot, they cannot interpret the data in the context of a planned mission (current weather reporting facilities for

<b>National/Worldwide Airline/Transport Weather Information Systems</b>		
	Weather Information Network (WINN)	<b>Honeywell</b> , ARINC, WSI, NCAR, AlliedSignal, United Airlines, COMSAT, Kavouras, Swissair, SITA, NWS/AWC
	Aviation Weather Information (AWIN) Implementation Team	<b>Boeing</b> , Federal Express, General Dynamics, Canadian Marconi, COMSAT, WSI, NCAR, AMS Enterprises, Rockwell Collins, FAA, USAF
<b>National General Aviation Weather Information Systems</b>		
	General Aviation-Oriented VDL Mode 2-Based Weather and FIS Broadcast, Reception and Display System	<b>NavRadio</b> , Aspen Mountain Airlines, Atmospheric Systems, Avidyne, Avrotec, EAA, FAA Civil Aeronautical Medical Institute, State of Minnesota, National Association of Flight Instructors, State of Pennsylvania, Raytheon Electronics, Regional Airline Association, Seagull, Unisys Weather Information Services, State of Wisconsin
	Weather Hazard Information System: Reducing Fatal GA Weather-Related Accidents	<b>ARNAV</b> , NCAR, Cessna, EAA, National Air Transportation Association, Small Aircraft Manufacturers Association
<b>Topical Projects</b>		
	Aviation Weather and Awareness Reporting Enhancements (AWARE)	<b>Rockwell Science Center</b> , Rockwell Collins, University of California, Irvine
	Enhanced On-board Weather Information System	<b>Rockwell Science Center</b> , Rockwell Collins
	General Aviation Oriented Electronic Pilot Report Generation and Datalink System	<b>NavRadio</b> , Aspen Mountain Airlines, Atmospheric Systems, Avidyne, Avrotec, D-TEK, EAA, FAA CAMI, Inertia Technology, NCAR, RAA, Seagull, Unisys Weather Information Services, State of Minnesota, State of Wisconsin
	Weather Avoidance Using Route Optimization as a Decision Aid	<b>Honeywell Technology Center</b>

**Table 1** Cooperative Agreements Awarded Under the AWIN Program

<b>Preflight</b>	<b>Enroute</b>
<ul style="list-style-type: none"> <li>- FSS weather briefers</li> <li>- Text-based reports</li> <li>- NEXRAD imagery</li> <li>- Satellite imagery</li> <li>- NWS weather charts</li> <li>- The Weather Channel</li> </ul>	<ul style="list-style-type: none"> <li>- FSS frequencies</li> <li>- Local airport advisories</li> <li>- Flight Watch</li> </ul>

**Table 2** Weather Services Available to the GA Pilot

GA are summarized in Table 2). If human weather briefers are not accessible, there is no credible replacement who can provide superior situation awareness to the GA pilot.

The current “state-of-the-art” in computer-assisted weather briefing is the DUAT service which provides a large variety of text-based weather products such as METARs, TAFs, FAs, PIREPs, SIGMETs, and AIRMETs. With or without the optional free text translation, DUAT provides pages of information which pilots are legally obliged to assimilate. The only contextual filtering supported by DUAT is at the state or regional level, meaning that the pilot of a 150 mile flight from Palm Springs to Las Vegas will receive current and forecast weather for all of California and Nevada, an airspace of over a million cubic miles! What the pilot really needs to know is all significant weather phenomena on or near the planned course of flight and around the selected flight level. A remarkable compression in the amount of data

can be achieved by such contextual filtering, thus increasing the signal-to-noise ratio for the information transfer and increasing the situational awareness of the pilot. Further gains in situational awareness may be achieved by emphasizing the potential impact of weather-related threats or hazards on the planned mission including the type of aircraft used and the type of flight plan filed.

A similar line of reasoning applies to ground-based radar. High-resolution NEXRAD (Next Generation Weather Radar) imagery is now available from NIDS (NEXRAD Information Dissemination Service) providers at 5 minute intervals and is a valuable resource for visualizing thunderstorms developing or active along a flight plan. However, the visual information is not correlated with the textual information available to a pilot. Furthermore, existing products do not support the assessment of storm kinetics or dynamics, i.e., whether a storm will approach a known flight path over time or whether storm growth or decay will have a meaningful impact on a flight plan.

#### *Enroute Weather Information*

The weather information problem changes character enroute. Once airborne, the GA pilot does not have access to the rich sources of raw data available to those on the ground: the pilot is usually limited to sparse information available via voice links and whatever is visible out the windshield. Fatal accident rates for GA are much higher than those for commercial air transport (AT), and weather

awareness is a common cause of many GA accidents and incidents. In 1996, there were 1.51 fatal accidents per 100,000 flight hours for GA vs. 0.28 for Part 121 AT operations in the U.S. Although weather awareness is not the sole culprit for the large disparity between the GA and AT accident rates, of the 11500 GA accidents between 1988 and 1992, over 3600 were attributable totally or in part to weather (National Transportation Safety Board statistics). A large percentage of fatal GA accidents are caused by non-instrument-rated pilots inadvertently flying into instrument meteorological conditions, or instrument-rated pilots flying into catastrophic weather conditions such as thunderstorms and low-level windshear.

There are several current efforts to increase weather awareness in the cockpit. In particular, several AWIN programs are addressing the very issue by investigating and implementing data links to provide real-time aviation weather data into the cockpit. For national coverage, the chosen technology is VHF data links such as VDL Mode 2, whereas for overseas and transoceanic coverage the preferred technology is satellite data links. Undoubtedly, the provision of real-time weather data into the cockpit will be a definite improvement over the current situation. However, data links are merely a partial solution and may not be sufficient to solve the weather awareness problem. To the contrary, the deluge of raw data into a busy cockpit may increase the pilot's cognitive workload. Therefore, we contend that the ultimate solution to the weather awareness problem in the GA cockpit requires not only real-time data link capabilities but also real-time weather interpretation capabilities. The AWARE program was conceived to demonstrate the feasibility of a complete solution to the GA weather awareness problem. The following section discusses the basic concepts of the AWARE program.

### 3. THE AWARE PROGRAM

The AWARE program is being conducted by Rockwell Science Center in cooperation with Rockwell Collins, Inc., University of California at Irvine, and NASA. AWARE is an enhanced weather briefing and reporting tool that integrates text-based and graphical aviation weather data for superior situational awareness in the context of a mission and equipment profile. AWARE is designed to benefit GA pilots who, due to cognitive overload, may not absorb and retain all flight-critical weather information from a vast stream of data that they are legally required to review.

Technologies being developed for AWARE include:

- Integration of data from commercial aviation weather sources such as DUAT and NEXRAD imagery;
- Integration of experimental graphical aviation weather products for icing, lightning, and turbulence;
- Decision support tools that capture the domain knowledge of experienced weather briefers and reason about weather-related hazards along a flight path;

- Tools and concepts for correlation and integration of weather data from multiple sources and modalities;
- A weather events database;
- A graphical user interface that assists the pilot in reviewing and understanding flight-critical weather events along a predefined flight plan.

Initially, the AWARE program will focus on the development of a prototype preflight briefing tool that will be accessible via the World Wide Web. During the fourth year of the program, the system will be ported to an EFIS (electronic flight instrument system) display and test-flown. It is conceivable that the VHF data link for the test flights will be provided by another AWIN program.

Figure 1 illustrates the system architecture for the preflight briefing version of AWARE. The rest of the section briefly describes the major functional blocks. The next section discusses relevant work that has been accomplished to date in NEXRAD image processing.

#### *Data Collection and Processing*

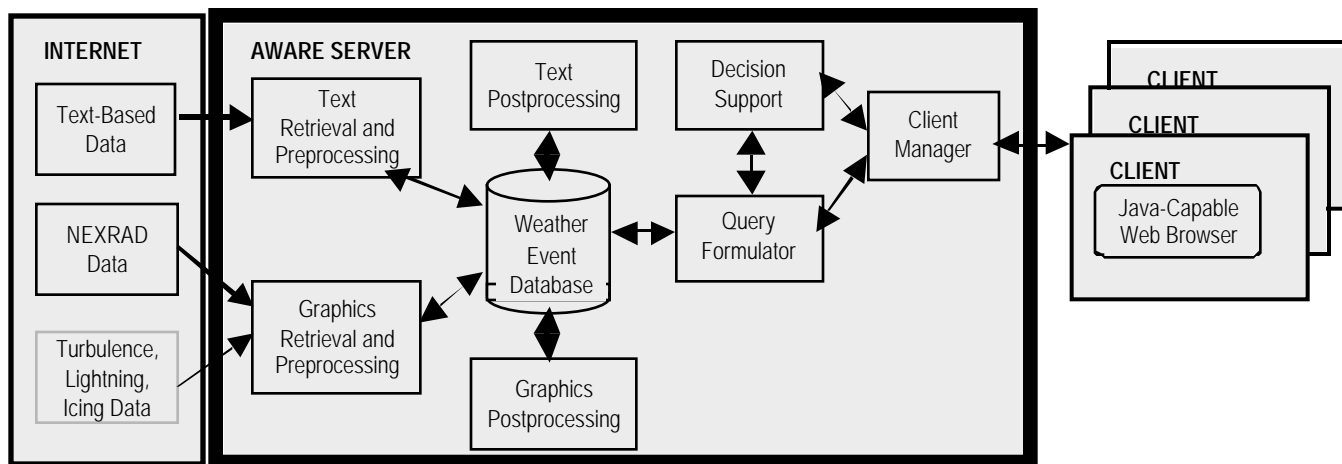
The AWARE system is designed to access aviation weather data sources at regular intervals to acquire and store relevant weather data. These data sources include text-based reports (METARs, TAFs, FAs, PIREPs, SIGMETs, AIRMETs, Convective SIGMETs, Winds Aloft, and NOTAMs) and graphical data sources (NEXRAD, satellite imagery, NWS weather charts, experimental aviation weather products such as turbulence, icing, and lightning charts). At this early stage in the program, it is unclear whether all these sources will be used for weather briefing and threat assessment purposes.

#### *Interpreting Text-Based Data*

We are currently developing tools for acquiring, parsing, and analyzing text-based weather data. In addition, we are developing tools for interpreting graphical weather imagery such as NEXRAD. Once text-based reports are parsed and radar images interpreted, the processed data will be stored in a database along with the raw data used to generate the interpretation. In addition, information about weather events available through multiple sources will be correlated and recorded as such. For example, information about a thunderstorm on surface weather reports (high winds, precipitation) can be correlated with NEXRAD imagery of the same storm and any associated turbulence reports or charts.

Another goal of the AWARE project is to generate intermediate graphical representations of the information provided in text-based reports. It is often the case that the geographical information encoded in text-based aviation weather reports is difficult to visualize. Consider the following icing and turbulence AIRMETs as an example:

```
AIRMET ICE ... WA OR CA
FROM TVL TO FAT TO BIH TO RNO TO TVL
```



**Figure 1** AWARE Preflight System Architecture

LGT OCNL MOD RIME ICGIC BTN 070 FL200.  
CONDS SPRDG SLOLY SEWD AND CONTG BYD 09Z THRU 15Z.

AIRMET TURB ... WA OR CA ID  
FROM EHF TO SMX TO SBA TO VTU TO PMD TO EHF  
OCNL MOD TURB BLW 120 DUE TO MOD WLY FLOW.  
CONDS SPRDG EWD CONTG BYD 09Z THRU 15Z.

Certain DUAT providers do a reasonable (but not entirely accurate) job in translating such reports to plain English text. A plain English report of the same AIRMETs might have the following information:

AIRMET Icing - Washington, Oregon, California  
From South Lake Tahoe to Fresno to Bishop to Reno to South Lake Tahoe  
Light occasional moderate rime icing in clouds between 7000 ft. MSL and FL200 (20,000 ft.). Conditions spreading slowly southeastward and continuing beyond 9:00 Zulu (GMT) through 15:00 Zulu.

AIRMET Turbulence - Washington, Oregon, California, Idaho  
From Bakersfield to Santa Maria to Santa Barbara to Ventura to Palmdale to Bakersfield  
Occasional moderate turbulence below 12,000 ft. due to moderate westerly flow. Conditions spreading eastward and continuing beyond 09:00 Zulu through 15:00 Zulu.

The plain English interpretation is certainly an improvement over the cryptic format used in text-based aviation weather reports. However, the English version still poses difficulties in visualizing the geographic extent of the weather phenomena and assessing whether the phenomena will have an impact on a given flight plan unless the pilot is intimately familiar with the locations of the airports used as spatial markers. Thus, the AWARE system will generate graphical representations of parsed

weather phenomena when necessary and present such information to the user graphically. Compare and contrast the text-based reports above with the equivalent graphical information depicted in Figure 2.

#### *Interpreting Graphical Data*

NEXRAD is a Doppler radar system that detects the relative velocity of precipitation within a storm [2]. A composite image assembled from 150+ sites is created by the National Weather Service at 5 minute intervals and subsequently distributed to and augmented by a number of commercial NIDS providers. Typical delay between the acquisition of NEXRAD images and distribution to users is approximately 8-10 minutes. Best resolution available on the national scale is 2x2 kms. per pixel.

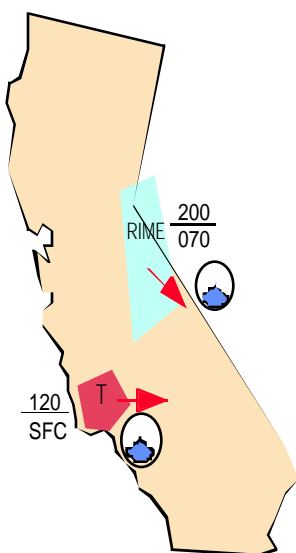
NEXRAD images, especially when reviewed in sequence, provide indispensable information about the extent, severity, and movement of thunderstorms. In order to extract such information from NEXRAD imagery, we have developed a Java class library for image processing. The functions can be classified in two categories: static and kinetic analysis. Static analysis works on single images whereas kinetic analysis works over sequences of images. In addition, we have plans to incorporate capabilities for analyzing storm dynamics in the future (i.e., detecting storm growth and decay profiles).

The functions available in the library are listed below.

*Thresholding*—This function selects storms that exceed a certain level of reflectivity (shown as color gradients on images where green depicts the lightest precipitation and magenta the strongest).

*Segmentation*—This function detects the boundaries of a contiguous group of pixels, i.e., a continuous area of precipitation.

*Grouping*—The grouping function takes as input the set of storm segments detected in the image and groups them



**Figure 2** AIRMET Depiction Concept

into logical storm clusters. For example, small areas of precipitation immediately adjacent to a large area of precipitation get clustered in the same group as the large area. The main benefit of the grouping function is that it facilitates the storm tracking function. Figure 3 illustrates some of the NEXRAD static image processing concepts.

*Growing*—This function is used for the grouping function. By growing storm segments radially either one pixel at a time or by a certain number of pixels at once, larger clusters of contiguous storms are obtained. These virtual clusters are marked as *groups*.

*Distance Measurement*—In certain instances, pilots want to know the minimum distance between storms in order to assess the possibility of safe passage. Although this can be accomplished by plotting the storm coordinates on a sectional chart and directly measuring the distance, an easier way is to select two storms on a NEXRAD picture and use the computer to measure the minimum distance. We developed two different algorithms to detect the minimum distance between two storms. The brute-force method calculates distances between all pairs of pixels on the periphery of the two storms, and is most advantageous when the storms are relatively small. The fractal method is similar to the method described in [3], and uses a minimax method that has  $O(n \log n)$  complexity for objects of reasonable shape where  $n$  is the number of pixels on the periphery of the storm image<sup>1</sup>.

*Storm Information*—The class library has facilities to generate and display certain categorical information about the storm such as area, size, extent, and maximum intensity.

<sup>1</sup> Worst case complexity of the algorithm is worse than the  $O(n^2)$  complexity of the brute force algorithm, but this mainly applies to certain synthetic examples and for most storm images the complexity is far more tractable.

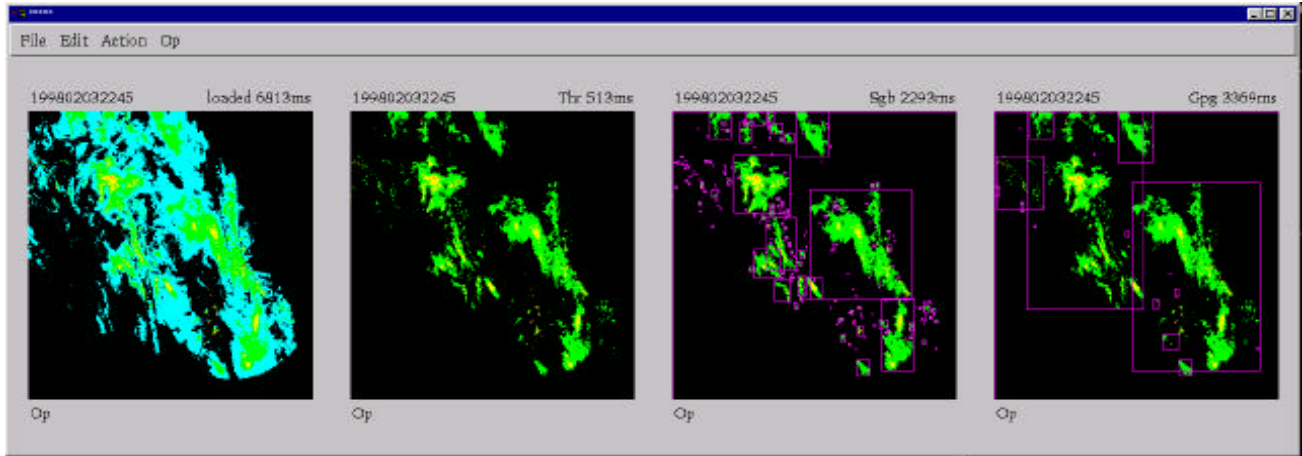
*Storm Tracking*—We have developed a simple technique to detect storm movement and to measure storm direction and velocity. In this technique, the user outlines a geographic area of interest on a sequence of NEXRAD images (imagine a sequence of two images for simplicity). The center of mass is computed for each image in the sequence. The relative motion of the center of mass between frames indicates the general direction and the velocity of storms captured in the viewframe. The first image is offset by this motion vector and superimposed with the second image. Storm shapes that intersect after the superimposition are then interpreted to be subsequent images of the same storm and marked as a *storm track*. This method has shown reasonably robust as long as the selected area is reasonably small and the storms within the selected area are part of the same air mass that moves in a given direction. The algorithm intuitively deals with storms splitting into two or two storms merging into one. However, several improvements are in order. For example, the algorithm does not yet account for shifts in the center of mass caused by storms entering or leaving the viewframe. In addition, the technique will break if the viewframe is large and the storms in the viewframe move in various directions. A better algorithm that does not use center of mass computations is under development. Figure 4 illustrates the detection of storm tracks on a sequence of four NEXRAD images.

#### *Decision Support*

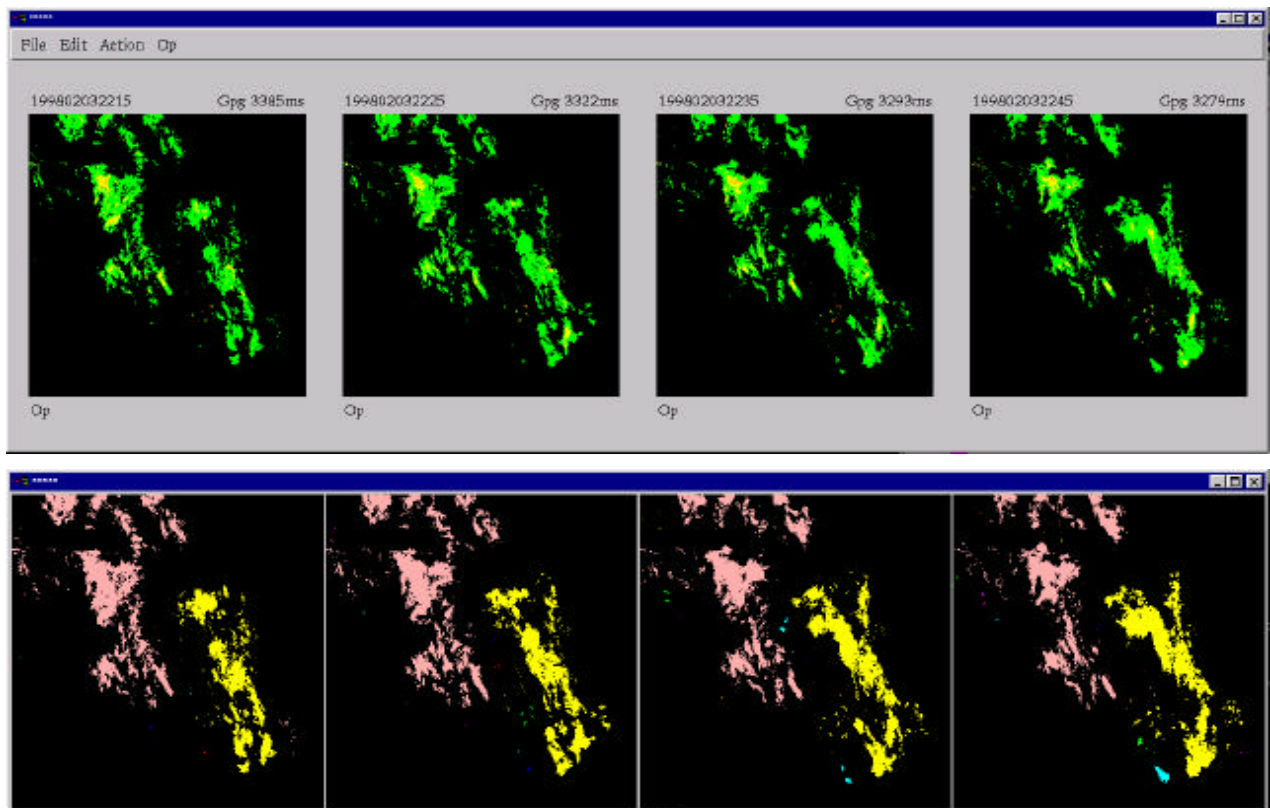
The decision support capabilities for AWARE are still under negotiation and development. As a minimum, AWARE will have capabilities to interpret the impact of known weather events on a given mission. A mission is defined by a flight plan, type of flight (VFR or IFR), pilot experience or preference profile, and type of equipment. According to Federal Aviation Regulations (Part 91.3(a)), the pilot in command is directly responsible for and is the final authority of the operation of an aircraft, and AWARE will not be allowed to make go/no go decisions on behalf of a pilot. However, AWARE will be equipped with the logic to critique flight plans on the basis of its interpretation of known weather events applicable to the time of flight. Due to legal liability considerations, information presented to the user will include all raw data in addition to the processed data and advice generated by the decision support system.

## 4. CONCLUSION

We are developing a system to assist GA pilots with weather awareness in the context of a mission and equipment profile. The program will run through 2002 and culminate in a proof-of-concept demonstration and flight testing of AWARE software. Most of the technologies described in this article are in preliminary development stages. Nevertheless, technologies that are under development are likely to improve on the state-of-the-art in preflight weather briefing and enroute weather assessment. AWARE holds promise as a tool that will assist pilots in bridging the cognitive gap between data and wisdom in interpreting aviation weather.



**Figure 3** Static Image Processing Capabilities (Left to Right: Original Image, Thresholded Image, Segmented Image, Grouped Image)



**Figure 4** Identification of Storm Tracks (Upper Series: Original Sequence; Lower Series: Storm Tracks Identified and Marked in Separate Colors)

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